Nonpoint Source Pollution and Diadromous Fish Restoration: An Analysis of Coastal Watershed Management Strategies and their Effectiveness

By

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Abstract

Human development has had damaging effects on coastal watersheds and estuarine environments worldwide. This paper considers the impacts of nonpoint source pollution (NPS) on these environments. Urbanization and agricultural practices have contributed significantly to the rising levels of NPS in these watersheds. Meanwhile, human development has also removed much of the natural riparian buffers that prevent NPS from entering bodies of water. As a result, water quality has decreased in areas where urban and agricultural development is present. In turn, this decrease in water quality has contributed to the decline of diadromous fish populations. These issues (NPS increases, water quality decreases and diadromous fish population declines) are investigated in the Merriland Branch Littler River watershed (MBLR) (located in southern Maine, USA) as well as several other coastal watersheds described by the scientific literature to face similar issues. Comparisons of the management approaches and actions employed in these watersheds are made to facilitate the development of a more comprehensive and highly integrated management framework. This management framework, referred to as the Precautionary Ecosystem Based Best Management (PEBBM) framework combines key characteristics of three commonly used coastal management frameworks: Ecosystem Based Management, Best Management Practices and the Precautionary Principle. The PEBBM framework is applied to the MBLR, outlining a basic watershed management plan.

Keywords: nonpoint source pollution, diadromous fish, estuarine, watershed, water quality, coastal management frameworks

Nonpoint Source Pollution and Diadromous Fish Restoration: An Analysis of Coastal Watershed Management Strategies and their Effectiveness

Chapter1: Introduction

1.1 The Management Problem

Many coastal watersheds around the world are experiencing problems related to poor water quality and habitat degradation. Human influences such as urbanization (contributing massive impervious surfaces and endless pollution) and agricultural expansion (producing great levels of excessive nutrients) are leading the charge in the advance of these problems. Excessive nutrients, chemicals and toxicants stemming from these areas are making their way into watersheds at an alarming rate.

Nonpoint source pollution (NPS) occurs in aquatic environments when levels of land based contaminants found in water become high enough to have an adverse effect on the ecosystem. This form of pollution is a rising problem in coastal watersheds and wetlands near urban and agricultural areas (Hong et al., 2010; Paul & Meyer, 2001). The use of agricultural fertilizers, lawn care products and urban runoff are the major source of these contaminates (Carpenter et al., 1998). Nitrogen (N) and phosphorus (P) comprise the most common of the excessive nutrients in question. Similarly, the vast expanse of asphalt, concrete, steel and otherwise impermeable surfaces in urbanized areas has resulted in the bulk of water runoff to flow directly into the watershed, rather than being absorbed by a permeable ground surface (Barnes, Morgan, & Roberge, 2001).

While nonpoint source pollutants are entering watersheds at increasing levels, the riparian buffers that were once able to filter out the excessive nutrients that lead to nonpoint source pollution are being destroyed to make room for human development (North Carolina State

University (NCSU), 1997). Riparian buffers are natural occurrences composed of grasses, shrubs and trees that cluster along the edge and banks of water bodies (Groffman et al., 2003). The type of development responsible for destroying these buffers has come in several forms, mainly urban and suburban sprawl as well as clear-cutting for agricultural purposes (Groffman et al., 2003). Once these natural filters are removed there is little stopping nonpoint source pollution from building in these watersheds.

These pollutants have the potential to negatively impact diadromous fish species (Greene, Zimmerman, Laney, & Thomas-Blate, 2009). The nutrients contribute to excess nutrification in the water body, resulting in eutrophication followed by hypoxia, anoxia, and otherwise poor water quality leading to fish kills in coastal watersheds (Carpenter et al., 1998). While these are not the only human induced factors causing fish populations to struggle, nonpoint source pollution and eutrophication are major concerns for the health of diadromous fish populations as well as for the ecosystems, fishers and economies that depend on these fish.

1.2 Research Questions

This study will attempt to address the following questions:

- What are the major NPS issues of concern affecting water quality as seen in North America and other regions of the world?
- How can these issues regarding coastal NPS be mitigated in such a way that water quality can be improved, allowing native diadromous fish populations to return to the watershed and thrive?
- What management strategies have been widely used to address water quality issues in coastal watersheds and how successful have these strategies been?

1.3 Methods & Research Strategy

In this study, management strategies and threats to water quality in the Merriland, Branch, Little River watershed (MBLR), a coastal watershed extending between the towns of Sanford, Wells and Kennebunk, Maine, will be reviewed and compared to other coastal watersheds documented in the literature, which have addressed and reported on water quality problems similar to those of the MBLR. Topics to be compared relate to water quality issues and the management strategies employed to address said issues. Through this comparison and analysis, management actions and frameworks yielding the greatest success will be pooled for discussion of how they operate and relate to one another. The MBLR was selected for this project as a central point of discussion on the basis of the author's participation in a fish habitat assessment in the MBLR, through an internship with the Wells National Estuarine Research Reserve (WNERR), Wells, Maine. Specifics of this internship based assessment will not be discussed in this paper as the assessment focused on barriers to fish passage, rather than pollution issues. However, the internship provided a background in local diadromous fish populations as well as a launching point for an investigation of nonpoint source pollution issues.

1.4 Objectives

There is need for improved connectivity between NPS management plans, water quality improvement strategies and diadromous fish population recovery efforts. While each of these issues is discussed thoroughly in the scientific literature, little effort has been made to incorporate the needs of a diadromous fish restoration into NPS and water quality management plans, and vice versa.

The objectives of the comparisons made in this paper are to: first, identify which management strategies are used to mitigate the negative effects of nonpoint source pollution in coastal watersheds; second, to determine which of these management strategies may have the greatest success in restoring water quality in coastal watersheds for diadromous fish populations to return to; and finally, to determine which of these strategies may be the most applicable to any coastal watershed-estuarine management plan. Recommendations to address these issues will be made first in a general sense. These recommendations will then be used to develop a combination coastal watershed-estuarine management framework, using the MBLR as an example watershed to construct such a management plan around.

The following chapters cover certain aspects of the MBLR watershed, diadromous fish, nonpoint source pollution and riparian buffers in extensive detail. This is done to facilitate understanding of these often complex components in the hopes of making the value of subsequent recommendations more apparent to the reader. That is to say, without a solid background in these components, the connections and relationships between them may be unclear. It is the understanding of these relationships and connections between watershed dynamics, diadromous fish, nonpoint source pollution and riparian buffers that management recommendations will be based on.

Chapter 2: Merriland, Branch, Little River Watershed

2.1 Physical Description & Geography

The Merriland Branch Little River watershed (MBLR) is located in Southern Maine, shared between the towns of Kennebunk, Wells and Sanford (Seacoast Watershed Information Manager (SWIM), 2006) (Figure 1). The watershed is 31.5 square miles (50.7 square km) or 20,176 acres (Smith & True, 2004). Drainage begins in the Sanford Regional Airport (with the Merriland River and Branch Brook tributaries) and empties into the Gulf of Maine via the Little River (Smith & True, 2004). The entrance point of the Little River into the Gulf of Maine is home to a substantial salt marsh with extensive biodiversity.

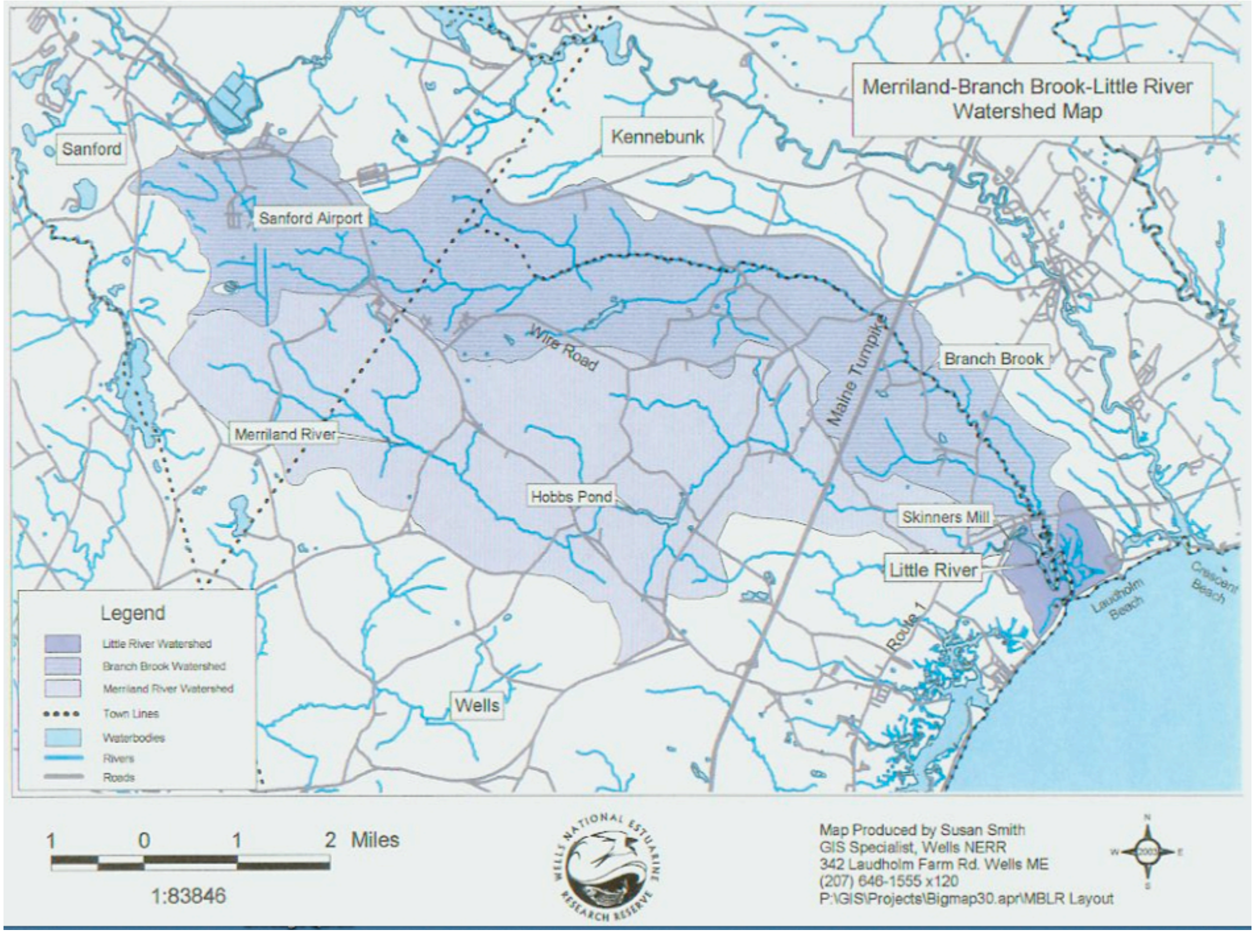

Figure 1. Map of Merriland, Branch, Little River Watershed. The highlighted region contains the entire geographic range of the MBLR watershed. Reprinted from *Merriland River, Branch Brook, Little River (MBLR) Nonpoint Source Pollution Management Plan* (p. ii), by T. Smith & H. True, 2004, Wells, Maine: Wells National Estuarine Research Reserve. Reprinted with permission.

The three major waterways of the MBLR watershed (Merriland River, Branch Brook and Little River) are fairly slow moving (outside of the higher flows of the spring thaw), meandering rivers (Wells National Estuarine Research Reserve (WNERR), 2002). Much of the sediment traveling down these water-ways consists of sand of varying grain sizes coming from the Great Sanford Outwash Plains, as well as glacial till and clay (WNERR, 2002). The fine-to-coarse grained sands that dominate this area are thought to originate from a large glaciomarine deposit (Weddle & Rettele, 2001). Such a deposit is the result of past glaciers scraping material from the neighbouring highlands and transporting it into the adjacent marine environment, leaving the Great Sanford Outwash Plains in its wake.

Along the coast of the MBLR lie a variety of habitats and ecological zones. Two major sandy beaches are found here, Crescent Surf Beach and Laudholm Beach (SWIM, 2006) (See Figure 1). Much of Crescent Surf Beach is privately owned with selected public access allowed. The Rachel Carson National Wildlife Refuge, also located within the MBLR, manages Crescent Surf Beach, posting signs and information related to conservation and protection of the biota that relies on the sandy beach, surf, dunes and grasses (U.S. Fish and Wildlife, 2009). The mission of the Rachel Carson National Wildlife Refuge is focused around restoring and preserving a diversity of coastal and estuarine habitats. The Wells National Estuarine Research Reserve (WNERR) in Wells, Maine, manages Laudholm Beach, located south of Crescent Surf Beach (Wells National Estuarine Research Reserve (WNERR) Protection, 2010). Laudholm Beach, unlike Crescent Surf Beach, has no human development along it courtesy of its protected status. WNERR is a research and education organization funded, in part, by the National Oceanic and Atmospheric Administration (NOAA) and locally from the Laudholm Trust. The mission of WNERR is to "expand knowledge about coasts and estuaries with an emphasis on ensuring healthy salt marsh ecosystems" and also to "…provide a scientific foundation for community effort to protect coastal watersheds" (Wells National Estuarine Research Reserve (WNERR) Research, 2010). This is done through endless research programs and educational opportunities, bringing in students and researchers from across the country. A vast network of recreational hiking trails run through the reserve to attract tourist and outdoor enthusiasts alike. Beach access is available through these trails; however, the conservation and protection efforts of WNERR are a constant reminder with signs posting critical information and rules along the way.

2.2 Protected Land & Acreage Breakdown

Outside of the Rachel Carson National Wildlife Refuge and WNERR, there are several other protected areas in the MBLR: Fenderson Commons, 600 acres managed by the Town of Wells; Kennebunk Plains, 645 acres managed by the State of Maine and the Nature Conservancy; Branch Brook, 1,947 acres managed by Kennebunk, Kennebunkport and Wells Water District (Smith et al., 2003). All of the conservation and protection efforts in the MBLR watershed have led to a total of 4,428 acres of land being protected or conserved within the watershed, totaling 21% of the land (Smith & True, 2004). The remaining land is divided as follows: vacant land, 41%; developed land, 25%; farm and tree growth, 13%. Vacant land may often look similar to farmland or active tree farm areas; however, the difference is that vacant land does not serve a specific purpose, such as crops, orchards or livestock.

These land use percentages are further broken down into four zoning classifications used in the watershed: Commercial/Industrial, 2%; Suburban Residential, 6%; Rural Residential, 80%; Conservation, 14% (Smith & True, 2004). At first glance, these numbers seem to have discrepancies with the aforementioned percentages. The difference is that the latter percentages consider “Conservation” as a category of its own, rather than pairing together conservation and protection, as seen in the prior set of land use percentages. Discrepancies aside, the take home message is that little of the land in the MBLR watershed is developed for industrial purposes, while much of the area is rural-residential. The conservation and protection effort in the watershed through the Rachel Carson National Wildlife Refuge and the Wells National Estuarine Research Reserve is seen to be brought by the local community into their own backyards. The importance of such stakeholder participation and cooperation will be referred to in subsequent chapters.

2.3 River Classes

Being one of the better conserved and protected watersheds of Southern Maine, maintaining the water quality of the rivers of the MBLR is of key importance. River classes in Maine are divided into three broad categories (A, B and C) based on the quality of water and regulations assigned to the river (Maine Department of Environmental Protection (DEP), 2005). The Maine Environmental Protection Agency (EPA) is responsible for assigning classification. Each of the three categories is then broken into further subcategories. Merriland River and Branch Brook are designated as Class A rivers (Smith & True, 2004). As described by the Maine EPA in Smith et al. (2003):

> Class A waters shall be of such quality that they are suitable for the designated uses of drinking water after disinfection; fishing; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation; and navigation and as habitat for fish and other aquatic life. The habitat shall be characterized as natural" (p. 1)

The Little River is deemed a Class SB, the S denoting its salinity level from the marine/estuarine component. Class B rivers maintain a relatively good water quality, although there are fewer restrictions and regulations on activities and uses permitted in the river (Maine DEP, 2005). The Little River has higher fecal coliform levels, which spike in late summer (Smith et al., 2003). These elevated levels of fecal bacteria make the river unfit for recreational activities, such as swimming and water-sports, which put people in direct contact with the water.

2.4 Uses & Resources

There are many uses of the MBLR ranging from recreational fishing and wildlife watching to supplying the area with drinking water (Smith et al., 2003). The Kennebunk, Kennebunkport and Wells Water District (KK&W Water District) have used the aquifer of the MBLR watershed for drinking water for over a century (WNERR, 2002). The waterways of the watershed are used for recreational boating, fishing and swimming. In particular, Hobbs Pond, an artificial pond created by damming Merriland River, is a popular recreational area year-round; ice-skating and hockey are popular winter activities.

The majority of the commercial uses of the watershed are possible because of the relatively clean waters of the rivers and streams and the protected lands associated with those waters. Rising fecal coliform bacteria levels in the mouth of the Little River have impacted commercial activities such as clamming, as harvesting is not permitted due to the bacterial contamination (WNERR, 2002). Tourism is another commercial activity that brings critical revenues into the towns of the watershed. One of the major attractions for these tourists refers back to the high quality of the watershed due to conservation and protection efforts (Maine Office of Tourism, 2011).

2.5 Threats To Water Quality

Although the MBLR watershed is a relatively clean and well-protected area, there are many threats to its water quality. These threats include riparian buffer removal, animal waste and associated fecal bacteria, urban runoff, surface erosion, impervious surfaces, canopy loss, snowmelt runoff, airport pollutants and chemicals, and clear-cutting near Hobbs Pond (Smith & True, 2004). More specifically, it is the toxicants, particulates and other chemicals that enter the water as a result of the aforementioned threats. The combination of these threats led to the development of a management plan for the MBLR watershed in 2004. Contaminants and pollutants from urban and agricultural runoff are problematic enough on their own. Waste from livestock contributes to the high fecal coliform levels of the Little River estuary (Smith & True, 2004). General urban and agricultural runoff carries with it many toxicants and chemicals associated with nonpoint source pollution. Such runoff has become an even greater problem as riparian buffers have been removed for development (Smith & True, 2004). The loss of these buffers has been observed in residential areas (both urban and rural) as well as commercial and agricultural areas. In residential areas, properties neighbouring the tributary are often built within such close proximity to the water that shoreline vegetation is completely removed, allowing landscape and pet waste to easily enter the water (Smith & True, 2004). In agricultural and urban areas this problem has been magnified as considerable buffer loss, due to clear cutting and development, allows runoff to carrying even more pollutants, nutrients and contaminants into the water.

Tree and vegetation removal nearest to riverbanks is suggested to have the greatest impact on water quality (Smith et al., 2003). A 25-100 foot (7.6-30.5 meter) zone of buffer on each side of the river is recommended for adequate runoff filtration in the MBLR. A survey of the watershed reports many areas of surface and bank erosion, which has been caused by the removal of vegetation buffers (WNERR, 2002). Also, a harmful side effect of tree removal near a riverbank is an increase in water temperature due to loss of canopy shade (Smith & True, 2004). Here, cooler temperatures inhibit excessive algal growth known to cause fish kills. In terms of erosion, the harder a raindrop hits the ground, the greater its erosive capacity is (WNERR, 2002). The canopy, therefore, also aids in erosion prevention as it breaks the fall of precipitation, decreasing its velocity before contacting the ground.

A golf course on the western side of the MBLR is a single, major commercial use of the watershed, which greatly contributes to poor water quality through its high runoff levels carrying with it a variety of chemical fertilizers. Stream buffers are minimal in the golf course area; one may suspect this was done to enhance the view for players. Roadways and railroad tracks passing through the MBLR are another major contributor to buffer and canopy loss (Smith & True, 2004). In addition, the runoff from roads is extremely hazardous to the adjacent aquatic habitats of which roads follow. Improper roadside buffers are most commonly found at intersections and other large impervious areas, for example, parking lots. The spring snowmelt sees a spike in runoff contaminants and pollutants as the winter snow banks have collected traffic wastes throughout the winter months. This being said, the land uses having boundaries neighbouring streams have the largest impact on the quality of water, as there is less opportunity (e.g. physical distance) for toxicants, nutrients, and other pollutants to be filtered by the ground or vegetation (WNERR, 2002).

2.6 Management Strategy Employed

The MBLR management plan relies heavily on Best Management Practices (BMPs) as components of the management strategy for the watershed. BMPs will be further described in following sections; briefly, BMPs take on many forms and functions, all revolving around mitigating modern, human-induced environmental problems (Ice, 2004). BMPs are particularly well-geared for management plans covering complex issues; the reason is that best management practices are often easy to put into operation and modify while still maintaining high effectiveness (Bishop et al., 2005). Until the implementation of the MBLR management plan, no clear management strategy was used. BMPs were selected for the management plan for two main reasons. At the time of the plan's creation, BMPs were thought by the plan designers to be of the better-known management strategies (T. Smith, personal communication, July 5, 2011). Along with that, BMPs address land use challenges, such as construction and development, which are issues being faced by the MBLR watershed.

2.7 State Regulations

State regulations, as detailed by the water quality classification system, address the kinds of issues related to nonpoint source pollution to some degree. For example, a river classified as a Class A waterway has certain restrictions imposed on it, dictating the development and activities that may take place in and around the waterway (Maine DEP, 2005). However, as has been seen in the Merriland River, a Class A waterway, riparian buffer removal and erosion are common problems that are leading to pollution and contamination in the watershed (WNERR, 2002). Issues such as these are not addressed as specifically as others, creating an imbalance in regulation of major threats to water quality in the watershed.

2.8 Current Research Projects

Several research projects, led by the WNERR, are currently underway in the MBLR. Projects of relevance to this paper are a migratory fish assessment, habitat assessments, water quality monitoring and a nutrient sampling project (M. Dionne, personal communication, August 15, 2011). While data availability of these projects is minimal at this stage, the end results should provide detailed information on the status of water quality and levels of nonpoint source pollutants in the MBLR as well as a better understanding of the health of diadromous fish populations and their associated habitats.

Chapter 3: Diadromous Fish

3.1 What Are Diadromous Fish?

Diadromous fish are species that migrate between fresh and marine environments for certain stages of their life cycle (Lassalle, Beguer, Beaulaton, & Rochard, 2008). Spawning and feeding are common reasons for these migrations (Lasalle et al., 2008). Generally speaking, diadromous fish spend the majority of their life in either fresh water or the marine environment, only migrating into the other environment for a brief window annually. A definite similarity between all diadromous fish species is that at some point of their life cycle they will occupy fresh, estuarine and ocean waters (Greene et al., 2009). Fish species that migrate from the marine environment into the fresh water for spawning are termed anadromous fish, while their reverse counterparts are referred to as catadromous (Lassalle et al., 2008). This paper will deal mostly with anadromous species, which are more common to northeastern North America. In any given geographic region these migrations likely overlap temporally between species, however, migration times are distributed over the course of the spawning season from one species to another.

The need for certain fish species to exchange environments for part of the year may seem unclear until taking into consideration the variation of ocean productivity with respect to latitude. Gross, Coleman, & McDowall (1988) may explain this phenomenon best:

> The contrasting directions of migration can largely be explained by the relative availability of food resources in ocean and freshwater habitats. Oceans are more productive than freshwaters in temperate latitudes, and anadromous species predominate. In contrast, catadromous species generally occur in tropical latitudes where freshwater productivity exceeds that of the ocean. (p. 1291)

Another part of the explanation of the need for such migrations has to do with the juvenile stage of the life cycle. To explain, the adults of an anadromous species, such as alewives common to New England waters, spend the majority of their time in the ocean, where productivity is greater, and therefore food is more abundant (Greene et al., 2009). However, when the time comes for spawning, freshwater environments in northern latitudes, having less productivity than do the oceans in these latitudes, may have more space for eggs to be laid and juveniles to develop. It's a simple case of a group of similar species evolving and adapting in such a way that allowed for an unoccupied niche to be filled. In the case of the North American diadromous fish species, freshwater habitats were available and conditions for spawning optimal at certain times of the year.

3.2 Habitats

Anadromous fish commonly lay demersal eggs, which are eggs that lie on the bottom of the fresh water body (Chase, 2010). Demersal eggs may lie freely on the bottom or may be attached to the substrate. The substrate which the eggs are dispersed upon may be of varying grain size but is usually required to be clean of algal growth and/or detritus, except in some instances where particular species may prefer an area of organic debris (Greene et al., 2009). Slow moving pools or shore bank eddies are often the site of egg deposition. Water velocity is critical not only for the eggs but also for the adults traveling against the current in search of a suitable spawning location. A flow velocity of which is too great will lead to the adult becoming exhausted as they enter 'sprint mode' (Castro-Santos, 2005). A velocity of 1.5 m/s is suggested to be the flow velocity at which most diadromous fish species are able to swim at prolonged pace mode. Flow velocities upwards of 4.5 m/s resulted in all fish species in a 2005 Castro-Santos study to swim in what was referred to as 'sprint mode'. When sprint mode is required, fish will sprint for short distances and rest in side pockets of slower moving water, if possible. If rest is not possible, the fish will become exhausted, likely resulting in unsuccessful spawning.

Salinity, pH level, temperature and depth are all important water quality characteristics, each with an optimum range required for fish survival. The optimum range for any given characteristic may vary from species to species as well as region to region (Greene et al., 2009). Dissolved oxygen (DO), though, is one of the more important variables (Green et al., 2009; Maes, Stevens, & Breine, 2007; Maes, Van Damme, Meire, & Ollevier, 2004) where a DO level of 5.0 mg/L is thought to be the minimum for successful spawning (Greene et al., 2009 & Maes et al., 2007). Adult fish have been observed to live in lower DO levels, however, it is rare that spawning efforts take place, let alone succeed, in lower levels.

3.3 Behavior & Distribution

Details of an individual fish's life history can be determined by analysis of the otolith, a structure of the inner ear (Elfman et al., 2000). Otoliths are sensitive parts of an organ used by fish to determine direction and orientation as well as linear acceleration (Morales-Nin, 2000). As otoliths accrete daily, analysis of diadromous fish otoliths has shed light on their life histories and migratory behavior patters (Elfman et al., 2000). Both the pattern of accretion and the concentrations of trace elements in the otolith allow researchers to determine a timeline of the individual's life, including information such as when, where, and the duration of their stay in a given environment. Whether catadromous or anadromous, fish generally only spend just enough time in their opposite environment (marine or fresh) to spawn or feed (Elfman et al., 2000). Some species also remain in this environment throughout their juvenile development. In some cases, such as that of the American shad, the first year will be spent in the fresh water environment where it hatched before beginning the adult migration cycle. Once it has entered the adult stage, the American shad lives in the marine environment until spawning season, when it briefly returns to fresh water (Elfman et al., 2000).

3.4 Role & Uses

Diadromous fish play a crucial role in the marine, estuarine, and freshwater food webs (Saunders, Hachey, & Fay, 2006). Diadromous fish are described as keystone species, meaning species that help maintain ecosystem-homeostasis when populations are healthy and thriving. In terms of the keystone species role of diadromous fish, their health and success can dictate that of the ecosystem of which they are a part. During spawning runs, diadromous fish are an invaluable source of food for organisms of all sizes who cohabitate in the spawning grounds (Greene et al., 2009). Diadromous fish may be preyed upon by mammals, reptiles, birds and larger fish as well as provide nutrients to the system through the decomposition of fish carcasses. For example, American eel are estimated to make up 25% of the biomass of their system (Greene et al., 2009). This calculation of biomass includes both the actual mass of the eels themselves at any given time as well as the mass they have contributed to the animals that have fed on them at that time, being a number of fish, bird, mammal (including humans) and reptile species (Greene et al., 2009).

Diadromous fish have been utilized by humankind in multiple ways for generations. The 1778 American shad run was reported to save George Washington's army in Valley Forge after a winter of near starvation (Greene et al., 2009). Atlantic sturgeon were used by early European colonists in ways besides mere nourishment; uses included gelatin production, windows made from the swim bladders, and clothing and book bindings made from the skin of the fish. Finally, American eel, offering one of the highest energy per unit mass ratios, have nourished human civilizations for centuries (Greene et al., 2009).

3.5 Threats

Threats to diadromous fish populations are numerous and increasingly difficult for fish to avoid. The three major threats to diadromous fish are poor water quality (Green et al., 2009; Maes et al., 2004), barriers to fish passage (Castro-Santos, 2005; Hall, Jordan, & Frisk, 2011), and overfishing (Green et al., 2009; Saunders et al., 2006). Poor water quality, often the result of nutrient loading, negatively affects diadromous populations by altering the formerly mentioned habitat variable optimums in such a way that puts them outside of the fish's optimum range. For example, increased sedimentation leads to substrates not suitable for eggs to attach to. Similarly, excessive nutrient loading results in expedited growth of algae and phytoplankton blooms, also known as eutrophication. These blooms use substantial amounts of DO, resulting in DO levels to drop, creating hypoxic conditions for diadromous fish (Maes et al., 2007).

Urbanization and agriculture are often responsible for nonpoint source pollution leading to poor water quality. The wide variety of excessive nutrients, contaminants and pollutants in these areas often run unimpeded into the water as development has removed the buffers that once filtered them. Contaminants refer to chemicals and toxicants found in high levels, but not yet having adverse effects on the environment and biota, while pollutants refer to chemicals and toxins found in levels high enough to negatively impact the environment and biota.

In areas where water quality is acceptable, diadromous fish populations may face yet another insurmountable obstacle, dams and other fish passage barriers (Hall et al., 2011; Saunders et al., 2006). Whether manmade or resulting from beaver activity, such fish passage barriers have been observed to completely inhibit spawning runs. For example, in Maine, alewives once migrated 320 km up the Penobscot River and 190 km up the Kennebec River (Saunders et al., 2006). Modern dams now greatly limit fish passage in these rivers and their tributaries. These dams, and others in Maine, began to appear as early as 1634 (Hall et al., 2011). By 1859 fish passage access to the full extent of the watershed had been reduced to a mere fraction of what it once was.

Possibly the earliest major threat to diadromous fish populations was overfishing (Green et al., 2009). Diadromous fish are particularly easy to catch during their spawning runs, as they are highly concentrated in great numbers as they move up rivers and streams. Setting any variety of basic fish net in a river during a fish run will yield an easy catch. American eel landings are roughly one third of what their maximum once was, while Atlantic Sturgeon landings dropped from seven million pounds in 1890 to a mere 10% of that figure in 1901 (Greene et al., 2009). Currently, the Atlantic sturgeon commercial fishery is under a moratorium (Greene et al., 2009). Sturgeon are at particular risk to any of the aforementioned threats as they have long lives and slow maturity rates (Musick et al., 2000). Resulting from their sluggish maturity, it takes years for an individual to be able to spawn. This creates quite a lethargic population recovery, even during a fishing moratorium.

3.6 Current Diadromous Populations

In the MBLR and surrounding estuaries and watersheds, diadromous populations have declined across the board (Dionne, Dochtermann, & Leonard, 2006; J. Aman, personal communication, May 2, 2011; Saunders et al, 2006). While numbers are low, a marsh survey in the York River watershed revealed that the mummichog was the most abundant anadromous species, followed by the Atlantic silverside, American eel and alewife, respectively (Dionne et al., 2006). Comparable observations were made by the author (via fyke net and gill net surveys performed as part of an internship with WNERR in May, 2011) in the MBLR as well as Shorey Brook, a watercourse residing in the Great Bay watershed of New Hampshire. In these unpublished surveys, mummichogs were the most abundant, often caught in double digits; American eels amounting in slightly fewer numbers; and alewives seen to be rare, collecting a total of three. These surveys were performed during the alewife migration time in the month of May. Similar trends have also been documented in estuarine watersheds outside of the northeastern U.S., (Fisheries and Oceans Canada, 2006; Green et al., 2009; U.S. Commission on Ocean Policy (USCOP), 2004).

The American Fisheries Society conducted a survey of North American marine, estuarine and diadromous fish species in 2000 (Musick et al., 2000). The survey took nearly a decade to complete. When finished, it revealed that not only are the majority of diadromous fish species either vulnerable or at risk of extinction, but the leading reasons for this are over fishing, habitat destruction and habitat degradation. This survey was done by first identifying stocks at risk and then using the best available information relating to stock dynamics to determine how serious the stock decline was (Musick et al., 2000).

Chapter 4: Nonpoint Source Pollution

4.1 Definition

There are many kinds of pollution, which are divided into two major categories: point source pollution and nonpoint source pollution (NPS). Point source pollution is easily identifiable in its output source (Carpenter et al., 1998). For example, a sewer drainage pipe or storm drain outflow are classic forms of point source pollution. NPS refers to pollution that comes from various sources that cannot be specifically identified. In the United States, NPS is the most common cause of water pollution (Barnes et al., 2001). NPS is most frequently generated by urban and agricultural areas where water runoff carries pollutants and contaminants into the tributaries of the watershed (Carpenter et al., 1998). Barnes et al. (2001) define nonpoint source pollution as:

> …forms of water pollution, which arise over broad land areas… with pollutants being conveyed to water bodies via overland flow rather than by pipes, ditches, or conduits issuing from factories or sewage treatment plants. This type of pollution is linked to land-use activities, and its severity is a function of land-use type and intensity, including the amounts of impervious surface and the frequency and magnitude of storm events. (p. 2)

The issue with NPS is that because a single, specific source is often not identifiable, it can be difficult to control. NPS is most commonly associated with water; however, it is also found in the atmosphere (Swackhamer et al., 2004). Atmospheric NPS and water based NPS can intermingle through evaporation and precipitation. NPS enters waterways in runoff during and after precipitation events, collecting toxicants, contaminants, nutrients, sediments and pathogens. This paper focuses on excessive nutrients, mainly N and P, derived from agricultural and urban activities. The reason for the focus on N and P is because the MBLR watershed has identified these nutrients as threats to water quality (Smith et al., 2003; Smith & True, 2004). Currently, WNERR is conducting a nutrient sampling project in the MBLR; the data being collected relates to NPS levels and concentrations.

4.2 Nitrogen & Phosphorus Cycles

To understand the role of N and P in nonpoint source pollution, one must first understand the fundamentals of the cycles with which these elements undergo on earth. Both cycles convert N and P, from one of their respective forms to another, as they naturally occur on earth (Campbell & Reece, 2005). To begin with the N cycle, plants cannot use gaseous, atmospheric N until nitrogen fixation has taken place (Campbell & Reece, 2005). This process converts organic, gaseous N into one of its inorganic chemical forms; it is these inorganic chemical forms that plants require (Figure 2). Biological fixation is the most common form of N fixation whereby microbes in the soil process and converts the gas to a form usable by plants as they absorb N with their roots. N is passed on to herbivorous animals as they feed on plant matter, who in turn pass it on to carnivores. When a plant or animal dies, the process of ammonification takes place as bacteria and fungi break down the carcass, again, converting the N from one chemical form to another (Campbell & Reece, 2005). Once in the soil as ammonium, either nitrification or denitrification take place. Nitrification is a process (also through biological action) that transforms N to a form usable by plants (Campbell & Reece, 2005). Conversely, denitrifying bacteria may return the N to a gaseous, atmospheric form via a slightly different process.

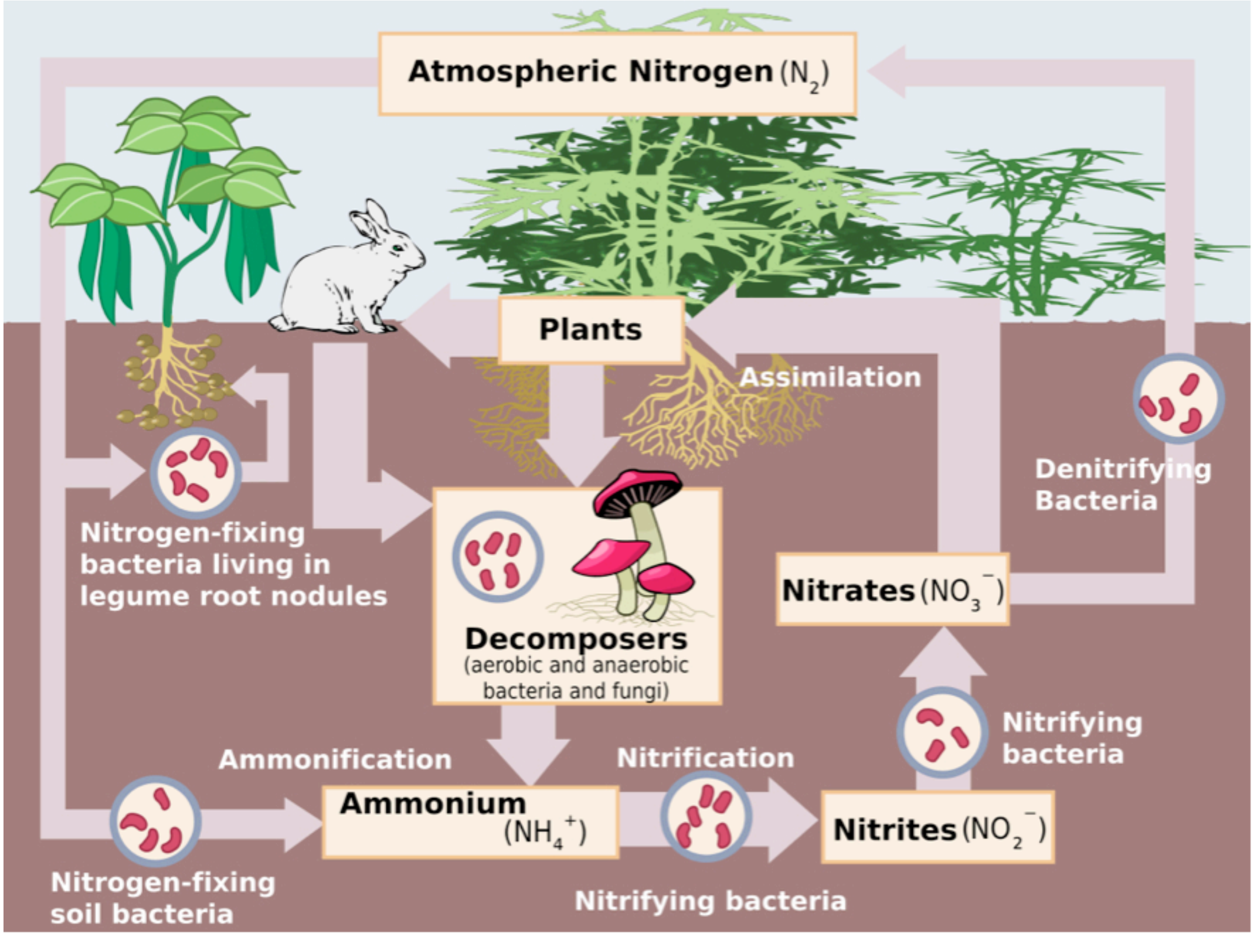

Figure 2. The Nitrogen Cycle. A representative flow diagram of the processes and components of the nitrogen cycle. Reprinted from Nitrogen Cycle, In *Wikipedia*, 2011, Retrieved August 16, 2011, from http://en.wikipedia.org/wiki/Nitrogen_cycle. Reprinted with permission.

In contrast to N, P exists mainly in solid form (Campbell & Reece, 2005). However, the P cycle does follow a pattern similar to that of N. Inorganic P first makes its way into the active P cycle as erosion carries P-bearing minerals from the terrestrial to the aquatic environment (Campbell & Reece, 2005) (Figure 3). Plants then use the inorganic P, followed in turn by herbivorous and carnivorous animals. Animal remains return P to the system as an organic form as decomposition converts organic P to its inorganic state where plants may use it once again (Campbell & Reece, 2005).

The chief difference between the P cycle and N cycle is that a large part of the N supply is in the gaseous form where P gas is rare, limiting P to dissolved solids in rock, soil and water.

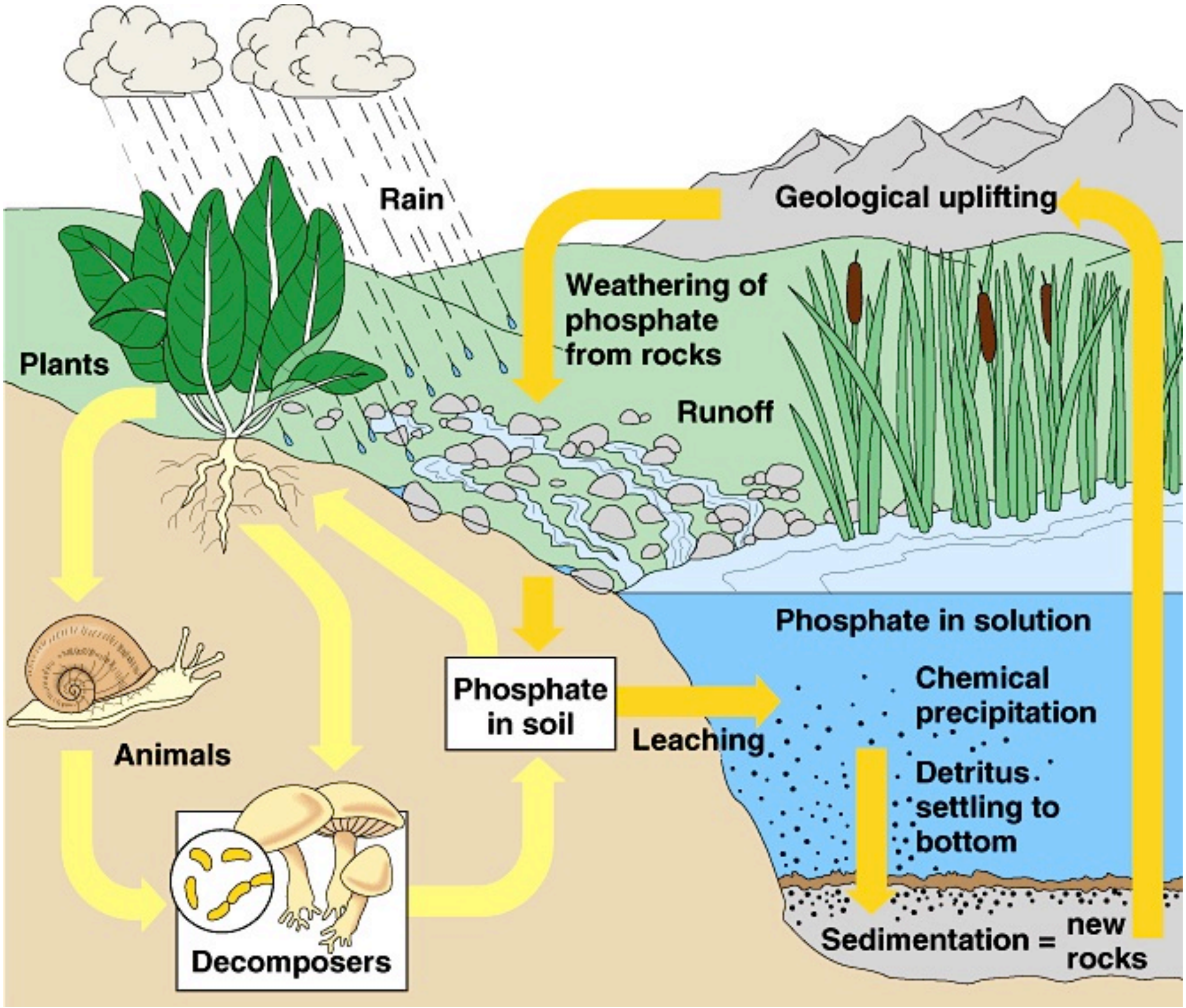

Figure 3. The Phosphorus Cycle. A representative flow diagram of the processes and components of the phosphorus cycle. Reprinted from *The Phosphorus Cycle and NC Water Quality*, by K. Gleason, 2005, Retrieved August 16, 2011, from http://phos-cyclenc.tripod.com/. Reprinted with permission.

4.3 Importance Of Cycles

These cycles are of great importance to the global food supply of not only humans, but to that of all life (Latimer & Charpentier, 2010). As has been described in a simplified sense, both N and P are nutrients needed for plants to grow. This fundamental understanding has led to significant human engineering in the forms of commercial, agricultural fertilizers. The application of commercial fertilizers has dramatically increased food production worldwide to a level that would otherwise be impossible to reach both physically and economically. Biologically speaking, N and P are important at the cellular level (Campbell & Reece, 2005). N is incorporated into amino acids and nucleic acids, which compromise a component of proteins. N also helps build DNA and RNA while P plays a key energy storage role, contributing to adenosine triphosphate, as well as aiding in the formation of DNA and RNA.

4.4 Anthropogenic Influence On Cycles

Modern humans negatively contribute to the N cycle by adding a surplus of inorganic N to the system (Elser et al., 2007). The N cycle naturally adds organic N to the soil through decomposition of plants, animals and their wastes. The agricultural revolution of mankind has led to the development of commercial fertilizers composed of inorganic N derived from mineral sources (Elser et al., 2007; Pearce, 2009). This N dependence began in the early 1900s when a method for removing N gas from the air was discovered (Pearce, 2009). This discovery allowed for efficient and effective production of inorganic N fertilizer. As understanding of this process improved, both N and P based fertilizers were produced in quantity (Elser et al., 2007).

Referring to the explanation and figures of the N and P cycles, one can see how the increase in anthropogenic sources of N and P can quickly throw these cycles off. These cycles can easily fall out of balance when anthropogenic sources of either nutrient are introduced into the cycle. While primary production quickly benefits from excessive nutrients, the heterotrophic organisms responsible for secondary production cannot consume the primary producers at a fast enough rate to maintain a healthy balance between the multiple chemical forms of N and P found in these cycles as well as between the population sizes of the primary and secondary producers in the system.

4.5 Impacts Of Nonpoint Source Pollution

4.5.1 Agricultural. Agricultural sites are often developed on or near river floodplains as these areas have fertile soils and readily available water. Commercial agriculture contributes a great deal of NPS into watersheds, mainly in the form of the nutrients N and P (Allan, 2004). Due to the use of commercial fertilizers, significantly more nutrients are added to the soil than are removed by the crops grown in the same soil (Carpenter et al., 1998). An estimated 400 million metric tons of excess P was left in the soil globally between 1950 and 1995 (Carpenter et al., 1998). This is a net estimation of what was left behind *after* crops used what they needed for growth, accounting for nearly two-thirds of the P added to the soil by farmers being left behind.

Livestock rearing is anther major contributor to NPS in agricultural areas as manure contains high amounts of N and P (Carpenter et al., 1998). This manure can easily be used as fertilizer for croplands; however, the amount of manure produced in large-scale livestock rearing operations far outweighs the amount of fertilizer that local crop farmers can use. This imbalance between meat and vegetable production might suggest that meat production should decrease; however, mankind's appetite for beef, chicken and pork will likely maintain the livestock industry as a highly economical one.

Allan (2004) suggests that waterways in agricultural areas remain relatively healthy until agricultural activities cover 30-50% of the land in the watershed. Rivers and streams in watersheds where the area of agriculture exceeds this percentage range have been found to sustain far fewer species than a comparable watercourse in an agriculture free area would be expected to sustain (Allan, 2004). This decrease in species diversity is seen in the aquatic and terrestrial habitats. Species that fill a more specialized niche are unable to adapt to the consequences of NPS, leaving the biological composition to largely be that of generalist species able to cope with fluctuating environmental conditions.

4.5.2 Urbanization. Urbanization, similar to agriculture, results in highly polluted runoff entering water bodies. The major characteristic of urban areas contributing to NPS is the huge amount of impervious surface in urban areas (Paul & Meyer, 2001). As described by Novotny & Chesters (1981) in Barnes et al. (2001): impervious surfaces are ‘hydrologically active’ as they do not allow water absorption into the ground, but rather transport water only over their surface. This effectively halts any filtration of harmful substances by the soil. Figure 4 demonstrates the different degrees of this hydrologic activity as it relates to the percentage of impervious surfaces in the urban environment.

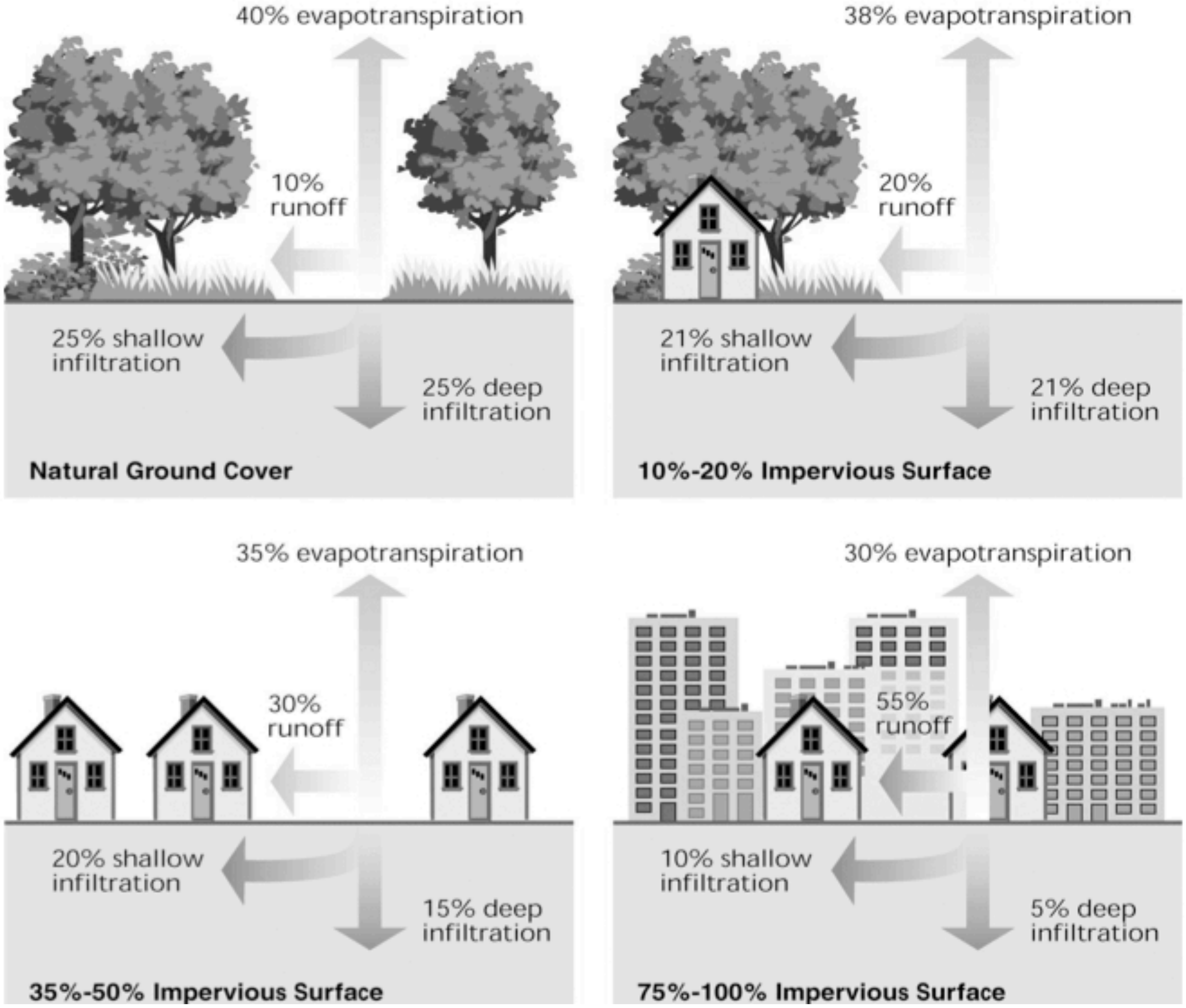

Figure 4. Impervious Surfaces. An illustration of the relationship between the percentages of impervious surfaces, runoff and evapotranspiration[1]. Reprinted from *Ecological Restoration of Degraded Aquatic Habitats: A Watershed Approach* (p. 149), by Fisheries and Oceans Canada, 2006, Oceans and Science Branch: Gulf Region. Copyright 2006 by Her Majesty the Queen in Right of Canada. Reprinted with permission.

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[1] The sum of water vapor from evaporation and plant transpiration from the surface of the land.

Impervious surfaces do also occur naturally; for example, exposed bedrock, clays, frozen ground and other compacted soils are all hydrologically active to some degree. Such surfaces generally allow some water to be filtered by the soil below, at least at certain times of the year when conditions are more favorable for filtration (Barnes et al., 2001). The impervious surfaces common to urban landscapes may include sidewalks, rooftops, roadways and parking lots.

Barnes et al., (2001, p. 1) describe impervious surfaces as posing the following threats to neighbouring water bodies: "increased storm water runoff, reduced water quality, higher maximum summer temperatures, degraded and destroyed aquatic and terrestrial habitats, and the diminished aesthetic appeal of streams and landscapes." Unlike agricultural runoff, increased sedimentation is not an issue in the urban environment, but rather, thermal pollution of waterways accompanies chemical and nutrient pollution in urban watersheds. Thermal pollution in the aquatic environment refers to the introduction of water of an abnormally high or low temperature. In the urban situation, the vast cover of asphalt has the tendency to heat runoff before it enters the water catchment (Barnes et al., 2001). Such a sudden rise in water temperature has the potential to stress or kill organisms living in the aquatic habitat where the runoff enters.

4.5.3 Other Sources Of Nonpoint Source Pollution. Following impervious surfaces, construction sites and landscaping are also major contributors to NPS. Natural processes, such as floods, erosion and fires are constantly altering the landscape. Humans have intervened with these processes in multiple ways as populations increase and technologies improve. Not only are floods blocked, fires put out and trees cut, but mountains are moved, ground is leveled and all sorts of human structures are constructed in the wake of this anthropogenic development. These human actions alter the natural geomorphic processes that healthy water systems depend on.

Landscaping and construction, on even a small scale, will result in altered flow rates from change in slope and/or loss of vegetation (Allan, 2004), as well as a surge in the amount of sediment, nutrient and other pollutants flowing into the water catchment (Carpenter et al., 1998). Mass construction in the urban environment has led to not only contamination and pollution of riverine environments, but also the total removal of these ecosystems (Paul & Meyer, 2001); streams and rivers are being filled in and built over as cities expand. One of the many negative results of this is that the concentration of NPS discharge in outlying water catchments increases as the tributary to urban runoff volume ratio decreases as urban expansion increases.

4.6 Eutrophication

Eutrophication is defined as "an increase in the rate of supply of organic matter to an ecosystem" (Pinckney, Paerl, Tester, & Richardson, 2001, p. 699). The increased organic matter, as discussed in this paper, refers to plant biomass of the eutrophic zone. This rise in plant biomass is the result of a nutrient influx in the water column. Unfortunately, the increased plant biomass is that of an increase in primary productivity (Paerl, 2009), being the autotrophic algal, cyanobacteria and plankton species that rapidly consume the added nutrients, causing a decrease in DO levels. An algal bloom of this nature will, therefore, harm the local fauna rather than contributing to the success of the ecosystem.

Similarly, this increase in primary producers and decrease in DO levels further exacerbates the effectiveness of the N cycle to remove excess N from the system (Howarth et al., 2011). The lower oxygen levels slow nitrification as well as denitrification. The retardation of these N conversion processes has two major impacts on the system: toxic forms of N build in the system as nitrification slows and excessive N is not removed from the water to be returned to the atmosphere as denitrification is further delayed. With these conversion processes slowed, sulfide levels rise, which inhibits further microbial conversion of N into gas, thereby locking it in the eutrophic water body.

4.7 Consequences

Consequences of eutrophication are commonly observed at a significant magnitude. Hypoxia and anoxia are common occurrences in estuarine systems troubled by eutrophication (Howarth et al., 2011); hypoxia characterizing low levels of DO, while anoxia is the complete absence of DO in the water. As described earlier, low or nonexistent DO levels in eutrophic environments are the result of massive algal blooms (primary producers) feeding on the excessive nutrients. DO is consumed by both the growing algal mass as well as the decomposers feeding on the dead algae (Howarth et al., 2011). Secondary producers, such as diadromous fish, are then subjected to suffocation, as there is not enough DO to support their respiration. Biodiversity of the area then decreases and, in turn, the system becomes increasingly vulnerable to collapse as key pieces to the ecosystem (such as keystone species) are lost. Compounding the problem of low DO levels and an otherwise unfit habitat is the rise in water temperature in the eutrophic zone (Fisheries and Oceans Canada, 2006). As algal coverage increases, the albedo of the water surface decreases. Similar to the higher temperature inside a black car on a sunny day compared to a white car, the amount of solar energy reflected by the water decreases as the algal population increases, thereby increasing water temperature.

4.8 Limiting Nutrients

To elaborate on the meaning of limiting nutrients, the concentration of these nutrients in an ecosystem will dictate the amount of productivity in said ecosystem (Paerl, 2009). N and P are considered the major limiting nutrients in reference to eutrophication events in fresh water, estuarine and marine environments (Elser et al., 2007; Paerl, 2009). In the case of an estuary or river, N and P are required at the first trophic level by autotrophs such as plankton and algae. These nutrients are deemed ‘limiting’ for multiple reasons. Not only are N and P required at certain, minimal, levels to maintain sufficient primary production for the higher trophic levels to build from, but also, a maximum level is a value of concern. Nutrient levels higher than necessary will result in over production at the primary trophic level (Paerl, 2009). Over production of primary producers *limits* the productivity of further trophic levels, as DO is consumed at alarming rates by these primary producers.

4.9 Autotroph Quality

It is important to understand that the levels of limiting nutrients on their own are not the only important factor for consideration when managing eutrophication. Similarly, the quality of the autotrophs responsible for processing N and P in the system is of equal value (Elser et al., 2007). Quantity of autotrophs tends to be driven by the amount of nutrients in the system. However, once the maximum, healthy, nutrient threshold has been surpassed, autotroph quality quickly degrades as nutrient levels rise. As autotroph quality decreases, processing efficiency for particular nutrients also declines. Autotroph quality, therefore, governs the success rate of such excessive nutrient processing and transportation processes needed to remove N and P from the system before hypoxia or anoxia take hold. Such autotroph quality correlates to the ratio of native vs. invasive autotrophic species inhabiting the system (Elser, et al., 2007). To elaborate, an organism (whether an autotroph or heterotroph) native to an ecosystem will better serve the ecosystem as the organism and system have evolved and adapted together over time. When an invasive organism replaces a native species, this co-evolutionary cooperation between the two is lost, usually yielding high success for the invasive species at the expense of the ecosystem.

Invasive autotrophs often enter the system once the eutrophican has reached a certain state of maturity. A mature eutrophic zone has experienced a large scale algal bloom where substantial diatom decomposition has taken place, diatoms being a major category of algae responsible for eutrophication (Howarth et al., 2011). These diatoms require dissolved silica for growth. As their numbers rise, dissolved silica levels in the system drop; the bulk of the silica is transferred from a dissolved state in the water column to a solid state deposited in the benthic zone. Such a drop in dissolved silica levels allows invasive diatoms, which require significantly less dissolved silica, to invade the system (Howarth et al., 2011). These invasive species of diatoms are precisely what is meant by the phrase ‘low quality autotrophs’.

4.10 Switch Of The Major Limiting Nutrient

Nutrient limitation in the estuarine environments has been seen to switch from one nutrient to another. Such a switch, when unexpected by management plans, leads to potentially far reaching impacts. For example, in the Mississippi River Delta area, a switch from N to P limitation was observed in the early 2000’s (Howarth et al., 2011). The cause of such a switch is likely due to many variables, such as climate alterations, nutrient input fluctuations, management efforts, biodiversity variability and the changing geomorphology and current flow patterns of the system. However, a transition from a high quality to a low quality autotroph dominating the system is a popular explanation (Howarth et al., 2011). The result of a switch to P limitation in northern Gulf of Mexico was that N-consuming autotrophs were outcompeted by those targeting P, effectively pushing the N lovers out of the system. Excessive N was then transported further into the gulf, rather than being removed in the initial eutrophic zone, as it had become characterized by P limitation. A new, N limited, eutrophic zone was observed to develop farther away from the delta, thus increasing the area harmed by eutrophication.

4.11 Interaction Of Nitrogen & Phosphorus Cycles

The interaction between N and P may not have been well understood until recently, however, research has suggested that the interaction between these cycles in the marine environment may be greater than once thought (Paerl, 2009). P induced eutrophication is more commonly seen in freshwater environment whereas nitrogen's influence is greater in the marine realm (Elser et al., 2007). The reason for this deals with the sources of the nutrients and the specifics of each cycle. What is important about this fact is that P problems upstream will have already impacted the biology of the system before even reaching the marine environment. As explained by Paerl (2009):

> Nitrogen-driven estuarine and coastal eutrophication has been, to some extent, exacerbated by P input constraints without accompanying N reductions in upstream lake and river systems, because the reduction in freshwater plant production in response to exclusive P input constraints has reduced the biomass that would otherwise have "filtered" N loads on their way to downstream N-sensitive estuarine and coastal waters. (p. 597)

Both cycles 'play off' of each other. Therefore, a problem with excessive P in a water system has the potential to exacerbate, or even initiate, an excessive N problem further down stream. Elser et al. (2007) suggest that levels of both nutrients are comparable and generally balanced in such a coastal watershed system. As a result, nutrification events induced by either N or P, throwing the system out of balance, allows for the opposite nutrient to swiftly attack the system. This is because as the system falls out of balance, the organisms and processes in place to manage any limiting nutrient will also fall out of balance, following suit of the system of which they are a part.

4.12 Geomorphology

As has been alluded to in earlier sections, local geomorphology of a river system and/or estuary, as well as that of the neighbouring ocean environment, also plays a crucial role in NPS distribution and processing (Allan, 2004; Howarth et al., 2011; Sweeney et al., 2004). At the freshwater level, similar variables important to NPS distribution and processing include such slope, soil composition, width, velocity and hydrologic connectivity [“water-mediated transport of matter, energy and/or organisms within or between elements of the hydrologic cycle” (Freeman, Pringle, & Jackson, 2007, p. 5)] (Allan, 2004; Sweeney et al., 2004). These factors determine how much of the excess N and P will enter the water. In the marine environment, certain geomorphologic variables will determine the level of susceptibility of the estuarine environment (Howarth et al., 2011). These variables include residence time, being the amount of time it takes for the pollutants to flush out of the estuary, and the extent of ocean stratification, referring to layering of ocean water of differing temperature and composition. These two major variables, in turn, are controlled by more general variables such as bathymetry, upwelling, wind patterns and water currents, all of which play a role in the flushing of NPS out of the estuarine environment.

4.13 Legacy Effects

Many modern day problems with NPS are considered “legacy effects.” This term references historical land use practices, which have since been prohibited, but were once harmful enough for their impacts to still be felt today (Allan, 2004). Often times, these legacy effects deal with geomorphologic alterations to catchment areas of a river, such as clear-cutting, agricultural development, urbanization or suburban land development. While the harmful land use practices have ended, legacy effects will be felt for years to come, even with modern management plans geared towards curbing such negative impacts on the environment. For example, New South Wales, Australia, saw multiple decades of vegetation clearing in water catchment zones as well as the draining of swamps and marshes to make way for development (Allan, 2004). Since then, a recovery plan has been implemented, thus far with little success. Legacy effects from the decades of misuse are responsible for the slow progress in recovery. The clear-cutting and swamp draining led to swifter downstream sediment transportation, resulting in the down stream area to be clogged with sediment and new vegetation while upstream is extremely sediment deprived. It is estimated that it will take thousands of years for the stream geomorphology to return to its natural, pre-anthropogenically altered state (Allan, 2004). Correlating with these changes in sediment deposition is the influx of excess nutrification, and therefore, eutrophication. To quote Allan (2004, p. 276): “not only does the valley rule the stream…but increasingly, humans activities rule the valley,” suggesting human impact on the system outweighs that of natural forces.

Chapter 5: Riparian Buffers

5.1 Definition

Riparian buffers contribute significantly to the filtering and removal of NPS (both N and P) from runoff and groundwater before reaching a river or stream (Broadmeadow & Nisbet, 2004; Mayer, Reynolds, McCutchen, & Canfield, 2005). As defined by Mayer et al. (2005, p. iv), riparian buffers are "the vegetated region adjacent to streams and wetlands…thought to be effective at intercepting and controlling N loads entering water bodies." The trees and shrubs that compose the riparian zone along a river are another multi-faceted role player in the watershed system. Not only do they act as filters, preventing certain forms of NPS (nitrates, for example) from entering the river from ground level, but the canopy of the buffer is also an active player. Shading from the canopy helps maintain a water temperature that organisms native to the system require (Allan, 2004; Broadmeadow & Nisbet, 2004; Kleinschmidt Associates, 1999). A study by Broadmeadow & Nisbet (2004) suggests that trees should shade roughly half of the stream surface while the other half remain open to sunlight exposure to aid in a healthy aquatic habitat. The leaves of the canopy slow the speed of raindrops, thus aiding in erosion prevention, while also contributing significant organic input to the system as leaves drop throughout the autumn months (Kleinschmidt Associates, 1999). This organic matter helps supply the ecosystem with food, shelter and nesting material for an array of aquatic organisms.

5.2 Threats & Destruction

A major threat to riparian buffers, as should come to no surprise, is human development (Mayer et al., 2005). Human development has devastated the complex ecosystems that once thrived in and around water catchments. Referring to this discussion of urbanization and agricultural development, the geomorphologic changes associated with these anthropogenic influences are also capable of lowering the local water table as runoff and drainage systems increase, by that means decreasing soil absorption (Groffman et al., 2003). Termed 'hydrologic drought,' this all-too-common phenomenon impacts the riparian zone by not only lowering moisture levels of soil, but also modifying the soil type, thereby dictating the plant species that are able to thrive in that environment. This is to say that a riparian buffer spared by chainsaws and bulldozers may still be at risk of collapse if hydrologic drought has infiltrated the ground below.

5.3 Optimum Widths

Buffer width is suggested as being an important variable when attempting to sustain a healthy and effective riparian buffer zone (Fisheries and Oceans Canada, 2006; Kleinschmidt Associates, 1999; Mayer et al., 2005). Minimum buffer width, as recommended in the literature, is seen to fall anywhere between two and 90 meters on both sides of the river. Broadmeadow & Nisbet (2004, p. 286) describe the potential benefits gained as buffer width increases: "buffer widths towards the lower end of this scale tend to protect the physical and chemical characteristics of a stream, while the maintenance of ecological integrity requires widths at the upper end." Clearly, a number of local variables will dictate the width of an effective buffer. Kleinschmidt Associates (1999) have developed one of the more comprehensive optimal buffer width keys, as listed below**.** A series of river and watershed attributes, as identified by Kleinschmidt Associates (1999) as variables useful in determining optimal buffer width, have been reproduced below. The more of these attributes than can be quantified for a site, the more successful the key will be. Attributes as identified by Kleinschmidt Associates (1999) are as follow:

Primary Attributes (most critical):

- Slope
- Soil type (as measured by soil hydrologic group)
- Vegetative cover (as measured by the degree of canopy closure)

Secondary Attributes:

- Surface roughness (ground vegetation, coarse woody debris, microtopography and forest floor)
- Surface water features (small streams and ponds within the buffer)
- Groundwater seepage/springs
- Sand and gravel aquifers
- Floodplains
- Wetlands
- Very steep slopes (i.e., >25%)
- Stream order

Kleinschmidt Associates (1999) have also divided riparian buffers into two zones. Zone one is described as being closest to the stream. Kleinschmidt Associates suggest that this zone be left completely intact to a minimum of 35 feet (10.7 meters) from the riverbank. While this distance likely should vary from one stream to another, the concept of maintaining a completely unaltered strip of vegetation closest to the water is sound. Zone two is described as the portion of ‘optimal’ buffer remaining once the first 35 feet (10.7 meters) have been subtracted. This zone may be used for activities that will not harm the overall integrity of the buffer, such as mild recreation and tree harvesting (Kleinschmidt Associates, 1999). The purpose of zone two is to support zone one both by physically protecting it from harsh environmental conditions while also assisting in nutrient filtration and soil retention.

Houlahan & Findlay (2004) report that increases of N and P can be detected when buffer habitats are damaged 4000m away, nearly forty four times the maximum buffer width as suggested by other studies. This staggering difference in findings merely suggests that optimal buffer width should also consider the size of the watershed in question. The amount of nutrients removed by riparian buffers varies greatly, depending largely on buffer composition, width, area of coverage, maturity and the amount of NPS flowing through the buffer (Mayer et al., 2005). However, studies have observed that a healthy wetland riparian buffer can filter out anywhere between 12-80% of N carried in runoff (Mayer et al., 2005). When pollution levels entering the system cannot be lowered, riparian buffers capable of filtering out pollutants may very well be the next best management strategy.

Chapter 6: Management Strategies & Actions As Observed In The Literature

This section will discuss similarities and differences between the MBLR watershed and other watershed and estuarine systems as reported in the scientific literature. A variety of other systems were reviewed for this comparison, including sites near and far from the MBLR, as well as ranging from similar dimensions to those of a more massive scale. Watersheds of a smaller area were not considered by this study for two main reasons. As the MBLR should be considered to fall on the smaller end of the watershed magnitude scale, the complexities of an even smaller watershed would likely be far too specific to be applicable to a general comparison study such as this. Moreover, the author observed that the correlation between the size of a watershed and the amount of information published on said watershed is high, yielding poor documentation of issues, activities and management efforts in the smaller watersheds. The purpose of the comparisons is to determine what characteristics of the MBLR watershed, and it's associated management plan (i.e. Smith & True, 2004), are either common to other coastal watersheds or possibly unique to the MBLR. These characteristics will be compared and contrasted between the MBLR and other watersheds with the intention of identifying patterns that lead to successful watershed and estuarine management strategies. The end goal of this is to make management recommendations able to maintain a high water quality level, which will aid in the restoration of diadromous fish populations.

6.1 Watershed Characteristics To Compare & Contrast

6.1.1 Nutrient Load Reduction. Efforts to reduce N and P loads are seen in other management plans (as identified and described in: Dionne et al., 2006; Hong et al., 2010; Kemp et al., 2005; Paerl, 2009) as excessive nutrification is the root of coastal NPS problems. Neighbouring the MBLR watershed, the York River watershed is similar to the MBLR in many respects. Shortly after publication of the *Merriland River, Branch Brook, and Little River Watershed Nonpoint Source Pollution Management Plan* (Smith & True, 2004), an assessment of the York River watershed was published by Dionne et al. (2006). This publication, entitled *Fish Communities and Habitats of the York River Watershed*, is similar to that which was required for development of the MBLR management plan. In the York River case, many of the same issues and suggestions were discussed as in the MBLR watershed. However, the York River publication placed less emphasis on lowering nutrient loads than did the MBLR management plan. To counter what may first appear to be an oversight of the importance of controlling NPS levels, Dionne et al. (2006) focused on riparian buffer conservation and restoration as well as noting areas of the report that require further study. This focus appears to have come from the understanding that riparian buffers play a vital role in many of the dynamics that shape and support a coastal watershed.

Researchers and managers of the Great Bay Watershed, a massive, estuarine drainage of New Hampshire, placed a high value on decreasing N loads into the Great Bay (Trowbridge, 2010). Trowbridge (2010) put forth that a calculated N load decrease of 30-40% is needed to maintain a sustainable estuary. While these figures by no means apply directly to the MBLR, it should be noted that the level of nutrient decrease recommended in the Great Bay watershed is rather high, suggesting that other New England estuaries, such as that of the MBLR, will likely also require major reductions in nutrient inputs.

Trowbridge (2010) have also initiated discussion for the development of a combination NPS and point source pollution management plan for the watershed of the Great Bay Estuary. While such a combination-pollution-plan has not been seen in the MBLR, other east coast estuaries have adopted comparable management plans. For example, in the Chesapeake Bay, row crop agriculture is responsible for the majority of the nutrients creating eutrophic zones in the bay (Weller, Baker, & Thomas, 2011). Meanwhile, the enormous geographic range of this watershed encompasses countless point source pollutant sites. These point source sites must also be better controlled for a eutrophication mitigation strategy to be successful. Officials throughout the Chesapeake Bay watershed have put forth “a series of agreements – involving all political jurisdictions within the watershed – to reduce inputs of both N and P from point and non-point sources” (Kemp et al., 2005, p. 20). Scientists and managers cooperated with the political arena in the development of this agreement. The agreement aims to lower nutrient inputs at large, while focusing efforts on several key habitat types.

There has been argument in the literature as to whether management of one nutrient (N or P) is more important that that of the other. Paerl (2009) provides evidence that management of both nutrients should be of greatest concern. Analysis of long-term data in the Neuse River Estuary, North Carolina, supports this claim. In the 1980s both N and P loads in the Neuse River Estuary were comparatively high. At this time, management policies mandated a reduction of P only as eutrophication was observed solely in the freshwater component of the system. Soon after the P reduction, algal blooms became a major problem in the estuary (Paerl, 2009). To explain, the P limited eutrophic zone in the freshwater portion of the system acted as a filter as the P limited bloom was also able to process N to a smaller degree. The P limited bloom also allowed dissolved N to settle as it moved downstream, and therefore, denitrification to take place. However, once the freshwater eutrophic zone was reduced, N freely passed into the estuary where N limited eutrophication commenced (Paerl, 2009). A series of events as well-documented as these provides strong support toward a dual nutrient management approach.

6.1.2 Habitat Restoration & Conservation. Habitat restoration and conservation is a common aspect of NPS management, which the author has observed to frequent the literature (e.g. Dionne et al., 2006; Haberstock et al., 1999; Mayer et al., 2005; USCOP, 2004). Restoration and conservation efforts are seen to take place both on the terrestrial sphere and in the estuarine setting. As seen in the MBLR, conservation and restoration efforts have been made by individual organizations (WNERR and the Rachel Carson National Wildlife Refuge) as well as by local municipalities and the state government (Smith & True, 2004). These efforts have conserved large portions of an assortment of habitat types both in the watershed and in the estuarine waters of which the watershed feeds.

A recently published, long-term study of water quality in the Elkhorn Slough watershed, emptying into Monterey Bay in central California, focused on restoration of terrestrial portions of the watershed, mainly through the reinstatement of riparian buffer zones (Gee, Wasson, Shaw, & Haskins, 2010). Five percent of the terrestrial acreage of the Elkhorn Slough estuary watershed was restored, half of that falling specifically in the riparian buffer zone. Post restoration monitoring found roughly a 50% reduction of nutrient concentrations in the water. Similarly, riparian buffer management and protection is a high priority in the MBLR watershed management plan. While riparian buffer restoration in the MBLR is relatively recent in comparison to the Elkhorn Slough Watershed, such high nutrient reduction rates, as seen in Elkhorn Slough, are encouraging when applied to the MBLR situation. While the Elkhorn Slough study suggests that riparian buffer restoration efforts could seriously improve water quality conditions in the MBLR, Gee et al. (2010) found that restoration and conservation of terrestrial habitats in the watershed was as important to water quality as was the restoration of estuarine habitats. To explain, the restoration and conservation efforts on land contributed as much to the success of the improved water quality as did similar estuarine-based efforts. The Elkhorn Slough study monitored a significant amount of estuarine habitat restoration. When data for each method of habitat restoration was analyzed, the success rate for the two was nearly the same, building a strong case for dual terrestrial-estuarine based restoration and conservation efforts to fall into the same management plan.

Other areas have placed a great deal of focus solely on riparian buffer restoration and conservation. For instance, in the Chesapeake Bay catchment, 59% of restoration projects were directed at riparian buffers (Weller et al., 2011). As NPS is documented as the leading source of excess nutrients in Chesapeake Bay, management strategies have relied on the filtration capacity of these buffers, similar to what was deduced from the aforementioned York River watershed publication. Following suit, the Piscataqua Region Estuaries Partnership (PREP: an organization overseeing a conglomerate of neighbouring New Hampshire and Maine estuaries) and the Massachusetts state government have conducted NPS studies of their own. Publications on these studies have suggested that riparian buffer restoration may be the most effective means of reducing nonpoint nutrient loading (Cole, Kroeger, McClelland, & Valiela, 2006; Piscataqua Region Estuaries Partnership (PREP), 2009).

The MBLR management plan recognizes the importance of riparian buffers and also implements state mandated zoning ordinances, which protect these buffers (Smith & True, 2004). In spite of this, the abovementioned ordinances take on a minimalist, one-size-fits-all, approach. Namely, buffer protection is only applicable to watercourses deemed ‘main branches’ of the watershed while the minimum buffer width is set at 75 feet (22.9 meters) (Smith & True, 2004). As previously explained, NPS runoff has the potential to flow into any tributary of a watershed while effective buffer width is a value that fluctuates greatly from stream to stream, depending on scores of locally-specific variables. Therefore, the minimalist approach leaves gaps in the plan, likely restraining achievement of certain plan objectives.

While the MBLR watershed, as a whole, does have a certain degree of riparian vegetation protection, this defense is not currently at the same level as in management plans presented by more 'illustrious estuaries'. This is not to say that small-scale operations have not been seen to make necessary changes to already existing plans and regulations. By way of illustration, Korea, in the past decade, has implemented massive changes to their laws as the need to improve quality of tidal wetlands and watersheds was marked with high value (Hong et al., 2010). With more modifications on the way, the goal is to ease the impacts of development on the landscape, thereby enhancing water quality. Improvements to regulations concerning vegetation buffers, protected corridors, and sensitive habitats were first initiated at village and city levels. Success at these levels has led to similar initiatives moving to the national level.

6.1.3 Education & Ocean Stewardship. Organizations in the MBLR such as the WNERR and Rachel Carson National Wildlife Refuge have shown impressive effort and dedication in their public education programs. Students and educators from all levels (as well as researchers and the general public alike) learn valuable insights and tips through a variety of programs and activities (U.S. Fish and Wildlife Service, 2011; Wells National Estuarine Research Reserve (WNERR) Education, 2010). Proper educational and awareness efforts are seen to be an immensely important aspect of a successful environmental management plan of any type (Ana, Oloruntoba, & Sridhar, 2009; Hostetler, Swiman, Prizzia, & Noiseux, 2008; USCOP, 2004).

Referring again to Korea, improved public education strategies are under development; the goal of which is to improve understanding of "tidal wetlands in maintaining healthy fish populations and reducing impacts of nonpoint source pollution" (Hong et al., 2010, p.1014). As a side note: the Korean example was seen by the author to best address the author's previously mentioned concern of the disconnect observed between management of NPS, water quality, and diadromous fish populations. Similar to education efforts in the MBLR, the public education strategies under development in Korea are fit to target a wide range of age groups.

Chapter 7: Discussion

Having performed a literature based review of coastal watershed and estuarine management issues and plans relating to NPS, this paper will now embark on a discussion of suggestions and recommendations aimed at curtailing the harmful impacts of NPS on coastal watersheds, improving water quality and enhancing the success and survival of diadromous fish populations. This is not to suggest that NPS reduction actions should be the only strategy used to restore diadromous fish populations. However, the connections made between NPS loads having a negative impact on water quality (Barnes et al., 2001; Howarth et al., 2011) and water quality governing the health of diadromous fish (Green et al., 2009 & Maes et al., 2004) suggest that NPS reduction is an important part of a coastal watershed management plan.

The Best Management Practices (BMPs) framework is observed to be an effective management strategy framework, widely used throughout other studies. The extensive use of BMPs in NPS and water quality related management plans does not contend that it is the *only* framework that may yield success. Two other management approaches have also been reviewed for discussion in this paper, one likely carrying even more vagueness with it than does the BMP framework (being Ecosystem Based Management - EBM) while the other is more direct and to the point (being the Precautionary Principle - PP). The application of the BMP, EBM and PP frameworks, along with their potential benefits, will be discussed. Specific recommendations will then be made based on the watershed comparison and other insights gained through the literature review. The strategies described in these recommendations will fit into one or more of the three aforementioned management frameworks. What is important is not recognizing which framework a particular action falls into, more so, it is to understanding that there are a variety of management frameworks which have had success in coastal management. Similarly, numerous actions exist that can be combined together and worked into an effective and integrative management plan. Proper integration of the frameworks and action items highlighted in this paper will improve connectivity between NPS management plans, water quality improvement strategies and diadromous fish recovery efforts, thus better serving the entirety of ecological components relevant to these three areas of concern in estuarine management.

7.1 General Recommendations From Current Management Frameworks

7.1.1 Best Management Practices (BMPs). The origin of Best Management Practices is rooted in the United States' 1935 Soil Conservation Act, an effort to reestablish land cover lost during the dust bowl period (Ice, 2004). BMPs have since been adapted to other terrestrial and aquatic management schemes. In terms of water quality, BMPs refer to supplementary measures that add an additional level of protection to maintaining a healthy aquatic system (Bishop et al., 2005). For example, a BMP for reducing the amount of excess nutrients entering a watershed may be structural, such as a retention pond, or non-structural, such as land use policy changes. BMPs, therefore, have the ability to play a crucial role in the alleviation of nonpoint source pollution problems in coastal watersheds. This explains the high frequency of BMPs incorporated into watershed management plans. With such adaptable and controllable actions (such as riparian buffer restoration and nutrient load regulations) BMPs make an excellent preliminary framework to design an estuarine-watershed management plan. While many coastal watershed management plans, including the MBLR plan, incorporate a variety of specific BMP actions, there is always room for improvement. Such 'room for improvement' does not suggest that the management plan in question was inadequately designed, but that as implementation of a plan proceeds, adaptations and modifications of the plan may be necessary to better suit the constantly changing ecosystems that the plan manages.

7.1.2 Ecosystem Based Management (EBM). EBM is an integrated approach to environmental management that considers the multiple factors (e.g. political, social, economic and environmental) that affect an area (Weinstein et al., 2007). EBM has been developing and evolving in the marine management sector over the past three decades (USCOP, 2004). The objective of this approach is to consider environmental and societal impacts along with those of a political nature when making management decisions (Osterblom et al., 2010). In a sense, EBM encapsulates the concerns and needs of all stakeholder groups to create an integrated plan that poses minimal threats to any one group. In cooperation with the highly specific actions stemming from the BMP framework, EBM rounds out a management plan by adding a broader sense of integration to the overall structure of the plan. Such integration is invaluable for the long-term success of a plan, courtesy of one simple relationship: as integration minimizes the negative side effects impacting any single stakeholder group, it simultaneously reduces the risk of collapse of the plan from lack of stakeholder cooperation.

Another advantage of EBM is that it considers how a single action will not only affect the target species or habitat, but also the entire suite of organisms and habitats associated with this target. The benefit of this is that the amount of unforeseen, adverse side effects, which may cause disturbances to the system, will be limited. For instance, in a river or estuary home to NPS and failing diadromous fish populations, a BMP based action plan incorporating EBM fundamentals would be better equipped to reduce excess nutrients and improving fish populations while also tending to the needs of other parts of the system influenced by the action.

7.1.3 Precautionary Principle (PP). The Precautionary Principle will be considered as a policy option for seeking alternative solutions to problems that are not fully understood. The origins of PP come from a 1930's German social-concept, *Vorsorgeprinzip,* which translates to "precaution principle" (O'Riordan & Cameron, 1994). The precautionary principle dictates that when the risks associated with an environmental issue or activity are uncertain, but could potentially be significant and cannot otherwise be quantified, the issue or activity must be considered harmful, for which an alternative is needed (Tickner & Geiser, 2004). Critics of PP claim it is more useful for simply labeling the problem while proponents of PP argue that its plasticity is better suited to find solutions to problems. In any case, it would be prudent for PP to be incorporated to some degree into a watershed-estuarine management plan. Seeing that such management plans must cover enormous tracts of land and water, both filled with incalculable uses, resources and variables, one must assume that risk associated with certain actions cannot entirely be determined. In such instances, the fundamentals of the precautionary principle should be applied. By so doing, management planners and decision makers are able to make choices that will be less harmful to the ecosystem.

7.2 Specific Action Recommendations

Incorporation of a diversity of specific structural and regulatory action items has the capacity to maximize a management plan's effectiveness. The wide variety of factors, players and variables at work in systems as diverse as coastal watershed and estuarine environments require a range of management frameworks, strategies and actions for progress to be made. The following action items have been observed to benefit coastal management plans dealing with water quality issues such as those faced by the MBLR watershed. For this reason, these measures are recommended in any management plan dealing with NPS, water quality or diadromous fish population restoration.

7.2.1 Joint Focus On Nitrogen & Phosphorus. The importance of focusing on the pair of major limiting nutrients was supported in multiple case study watersheds discussed above. As was seen best in the North Carolina example, N and P have a dynamic and closely coupled relationship. Ignoring either of these nutrients in a nutrient reduction strategy can quickly lead to similar eutrophication problems in other areas of the ecosystem. Management plans addressing how to control excess N and P from the onset are far less likely to encounter a shift of the eutrophic zone from one section of the ecosystem to another.

7.2.2 Joint Nonpoint & Point Source Pollution Reduction Strategy. Similar to the benefits of a joint N and P nutrient reduction plan, combining efforts to reduce NPS as well as point source pollution has also yielded success. Multiple pollution plans, each dealing with different kinds of pollution (e.g. nonpoint source or point source), may result in implementation gaps. The more general or vague pollution issues will inevitably be ignored by all sides involved in a multi-plan situation, each side having the expectation that one of the other sides will address the issue. Therefore, a single pollution management plan addressing all forms of pollution will be more effective as such implementation gaps are eliminating.

7.2.3 Riparian Buffer Conservation & Restoration. As shown above, the health and distribution of riparian buffers greatly influences the level of excessive nutrients in rivers and estuaries. Throughout the scientific literature, varying distances for both minimum and optimal buffer distances have been suggested, accompanied by strategies and formulas to calculate these values. While the author of this paper suggests the utilization of these methods to determine appropriate buffer width in a management plan, he also suggests applying a ‘common sense’ method to each situation. A common sense approach is important because while the literature has provided useful examples and background information, not all situations will respond the same to any given management strategy or action. This may be due to a previously unrecognized variable making its presence felt or, perhaps, a certain combination of variables interacting in an unexpected manner. Once formal analyses and calculations have been done, the results could be discussed in round table fashion with participation of both expert and local knowledge. Such a discussion will yield better understanding of the local specifics of the watershed and its associated variables as well as the technical details for the management planners to incorporate into a thorough and integrated plan. Broadmeadow & Nisbet (2004) add to this point with the following:

> Within the management of riparian woodland there is a need to consider a stream's sensitivity and intrinsic value. Some sites will benefit from active intervention such as thinning, coppicing[2] or pollarding[3], while others will be favoured by a hands-off approach. (p. 286)

While this advice was directed at freshwater environments, the benefits will surely be felt downstream in the estuarine and marine environments.

7.2.4 Wet Habitat Protection. Along with terrestrial habitat protection, such as that of riparian buffer zones, efforts to conserve and restore habitats in and under the water should also be made as part of the complete, ecosystem oriented management plan. Being that any one piece of the system is unavoidably linked to all other pieces, efforts to improve all types of habitats in the ecosystem will surely contribute to the overall success of the management plan.

7.2.5 Education & Awareness Campaigns. Public education and awareness of the issues at hand are critical for the sustained success of a management plan. As the general public stakeholder group is often the largest of all groups, the need for cooperation from this group is vital for proper implementation of action items. Appropriate cooperation from the public requires a certain, fundamental understanding of the situation and issues at hand. Therefore, education

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[2] The regular trimming of a thicket or dense growth.

[3] The cutting back of a tree to nearly the trunk, so as to produce a dense mass of branches.

and awareness efforts should be designed to reach a broad audience in a way they are able to relate to, thereby holding their interest and deepening their understanding of the problem. Not only will this enhance public cooperation, but it will also enable the public to participate to a greater degree in management efforts.

7.2.6 Monitoring & Evaluation. Monitoring and evaluation are two very basic components that all management plans should incorporate. With a lack of monitoring and evaluation comes a decline in a management plan’s effectiveness. To remain highly effective, a plan needs a human constituent to systematically observe, measure and assess all components of the plan in order to determine what actions and strategies are no longer facilitating progress. Long-term implementation of these steps will allow necessary changes and improvements to be made along the way in order to better serve the end goals.

Chapter 8: Recommendations For A Merriland, Branch, Little River Master Management Plan

The results from the projects currently underway in the MBLR (as described in section 2.8) should prove to be of great help in the update and modification of the current MBLR Management Plan (i.e. Smith & True, 2004). Until then, recommendations will be made for the MBLR watershed based on the Chapter 7 discussion and published MBLR information. A single, comprehensive and integrated management framework, composed of fundamentals taken from the aforementioned management frameworks (BMPs, EBM and PP), will be described. The use of such a framework is recommended for the MBLR and similar watersheds facing issues with water quality, NPS and struggling diadromous fish populations.

8.1 Combination Coastal Management Framework

This paper will now develop a single management framework composed of the most advantageous aspects of BMPs, EBM and the PP. This framework will take into consideration the understanding of the threats to coastal watersheds and diadromous fish as well as effective water quality and NPS management actions and strategies, all of which have been described in detail in previous chapters. This framework will be referred to as the Precautionary Ecosystem Based Best Management (PEBBM) framework. The purpose of developing such a plan is to offer the most useful and relevant aspects of modern marine management frameworks and plans in a single, highly effective management framework.

EBM will be incorporated into the core of PEBBM. EBM brings its integrated approach and value of the environment to the PEBBM framework. These qualities emphasize the importance of valuing the needs of the ecosystem in conjunction with the needs of stakeholders. The BMP framework then contributes a second layer of security with its highly adaptable, supplementary measures. The ease with which BMP actions can be modified to better fit a specific situation is what gives this component of PEBBM its value. Similarly, a wide range of BMP actions have been used and described thoroughly in the literature, making for excellent reference material for the development of a PEBBM based coastal watershed management plan. PP is then integrated into PEBBM for its capacity to assess risk and minimize the impacts of uncertainty. This final layer of protection is needed by PEBBM to ensure that high-risk decisions do not hinder implementation progress or success.

PEBBM will be able to better address the management problem identified at the start of this paper: i.e. the disconnect observed between NPS reduction actions, water quality improvement strategies and diadromous fish population recovery efforts. The comprehensive and integrative approach taken by PEBBM balances the tangible components in a coastal watershed management plan (e.g. stakeholders, organisms, habitats, etc.) with the intangible components (e.g. policy design and implementation, action strategies, risk, uncertainty, etc.). This balance allows PEBBM to recognize and address the needs and/or concerns of each of these components. The capacity to mitigate any threat to the overall socio-environmental system while also maintaining or improving the quality of each component is what gives PEBBM its integrated and comprehensive qualities. This makes PEBBM an optimal framework for a populated coastal watershed (such as the MBLR) faced by the issues of NPS, poor water quality and struggling diadromous fish populations.

8.2 Merriland, Branch, Little River Watershed Precautionary Ecosystem Based Best Management Plan

Development of a management plan for the MBLR watershed using the PEBBM framework begins with an assessment of the needs of the components that constitute the watershed's total socio-environmental system, meaning the social, environmental and economic components are considered. Specifically, such components of the watershed include: residents; businesses; industry; along with terrestrial, marine and estuarine organisms and habitats. Specific to the concerns of this paper are diadromous fish populations and the human activities contributing to NPS and poor water quality. Once assessment of these components has been made, the relationships between them and the threats that they face (e.g. agriculture, urbanization, development, riparian buffer removal, NPS, etc.) must be identified and assessed. Research projects currently underway in the MBLR (such as the diadromous fish assessment, habitat assessment, water quality monitoring and nutrient sampling) should provide the information necessary to make these assessments relative to the diadromous fish component of the MBLR.

Specific BMP action items must then be selected to either address the identified threats or to maintain current standards where acceptable. Action items to be used in the MBLR have been described in section 7.2. Specifically relating to diadromous fish restoration in the MBLR, emphasis on NPS management strategies should come in conjunction with other migratory fish restoration actions, such as barrier removal. Although the current status of NPS in the MBLR is under study, NPS has been identified as being a threat to the MBLR's water quality (WNERR, 2002). The concern is that while the 2002 survey of NPS (WNERR, 2002) found relatively small amounts of NPS in the MBLR (in comparison to larger watersheds, such as the Great Bay Watershed) the comparatively small size of the MBLR leads one to assume that even small amount of NPS may have a damaging effect in the MBLR.

In following the fundamentals of EBM, the selection of specific BMP action items for the MBLR should correspond with an evaluation of the degree to which such actions may negatively interfere with other components of the watershed. This is to ensure that action items directed toward a specific issue or target species do not have harmful side effects for other components of the environment. In instances where the level of uncertainty and risk involved is unacceptable, fundamentals of the PP should be employed to seek a safer solution. End goals and objectives for the approved action items should then be set to give the management plan direction. NPS reduction, improved water quality and the restoration of diadromous fish populations native to the MBLR should be considered as long term goals.

Before implementation of the plan, monitoring and evaluation standards and schedules must be developed to insure that the efficiency and effectiveness of the plan is maintained at a high level. As the MBLR sees dramatic seasonal fluctuations in activities responsible for NPS (such as crop growing and construction) as well as very specific migration patterns of diadromous fish, a seasonal monitoring program may best serve the management plan. Such a monitoring program for NPS would measure NPS levels following the winter melt, mid growing season, and after the harvest. Monitoring of diadromous fish populations must correspond with the known seasonal migration period of each species. Evaluation of the plan should be done on an annual basis, potentially during the winter months when monitoring-related fieldwork is limited. Annual evaluation allows for patterns of progress (or a lack of progress) to be closely tracked, benefiting the effectiveness of the modifications made to improve the plan.

Designing and implementing a MBLR management plan as described above would surely be a significant undertaking, requiring commitments and cooperation from a range of stakeholders. However, the benefits of such a PEBBM based management plan would outweigh the hardships required to initiate the plan. The design of the PEBBM framework allows for these benefits to be shared by all stakeholders, as well as the environmental components, of the watershed.

Chapter 9: Conclusion

Estuarine systems, as well as their freshwater and marine counterparts, are highly sensitive environments that have co-evolved with the organisms that inhabit them over great extents of time. Anthropogenic influences have seriously harmed these ecosystems over the past century or so. This paper has investigated several issues pertinent to the Merriland, Branch, Little River watershed (MBLR), located in southern Maine, USA. Specifically, the contribution of nonpoint source pollution (NPS) to the decline of diadromous fish populations has been considered. A literature review provided insight into management issues and remediation strategies of other coastal watersheds. Overall, a disconnect was identified in management plans between NPS reduction actions, water quality improvement strategies, and diadromous fish restoration efforts. In the case of the MBLR, the importance of NPS reduction and diadromous fish restoration has been acknowledged. However, the connection to water quality shared by these issues is not yet properly addressed in a formal management plan.

When considering how to best address issues associated with NPS, water quality and diadromous fish restoration, a management plan must take into account not only the anthropogenic causes of the problem, but also each of the many other components of the ecosystem that have been affected by NPS and poor water quality. While the impacts to larger heterotrophic species may be more obvious, such as declines in diadromous fish populations, one must remember that dozens of other species in the ecosystem have likely also been affected. Similarly, remediation efforts specifically targeted at certain species and/or habitats can unintentionally harm other ecosystem components. For these reasons, management plans should consult multiple management frameworks to increase the effectiveness and efficiency of the plan. The frameworks of BMP, EBM and PP were incorporated into the development of a highly integrated and comprehensive management framework, the Precautionary Ecosystem Based Best Management (PEBBM) framework. The BMP framework offers to PEBBM countless action items capable of mitigating the harmful consequence of nonpoint source pollution while EBM curbs unforeseen side effects of the implementation of such actions. PP fundamentals round out the PEBBM framework by exercising caution before and during plan implementation to avoid any impediments to progress. A MBLR management plan using the PEBBM framework would safely reduce NPS in order to improve water quality for the benefit of diadromous fish populations. In turn, stakeholders and ecological components alike would share the benefits of improved water quality as the needs of the entire ecosystem are considered.

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